pupal cocoons were found in August, then one may conclude that the product was not contaminated at the manufacturer site.

Diapause provides a means for the species to overwinter or survive periods of adverse environmental conditions at higher latitudes in unheated situations. The extent to which different strains diapause varies greatly, and those from the tropics or long reared in laboratories showing a reduced capacity. Diapause induced in response to short photoperiods (Bell, 1976), low temperature, or high population pressure (Tsuji, 1963) may greatly extend the developmental periods. At the limits of its range, IMM may have only one to two generations per year, but as many as eight generations per year may occur in warmer climates (Tzanakakis, 1959; Stratil & Reichmuth, 1984). Therefore, the use of the larval developmental time under the prevailing room temperatures is cumbersome to determine the moment of the product contamination by the IMM larvae. Only during warm months it is possible to indicate the time (and place) of product contamination when live larvae of the IMM or live pupae in the pupal cocoons are found within the infested product.

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Susceptibility of dried berries to infestation by *Plodia interpunctella* (Lepidoptera: Pyralidae) in correlation with total sugar content

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Abstract

By assessing the degree of resistance of stored products to infestation by insect pests and correlating it with physical, chemical and nutritional characteristics of products, we could gain a real insight in these pests feeding preferences, and consequently in their biology and ecology. The aim of this study was to assess the degree of resistance of five dried berry species (strawberry, raspberry, blackberry, black chokeberry and cranberry) to infestation caused by the major pest of dried berries, *Plodia interpunctella*. Susceptibility was rated based on the Index of susceptibility (IS) for insect development and the Susceptibility rating. Dried cranberries were

absolutely resistant to infestation by *P. interpunctella* (IS = 0) - no larvae reached the adult stage. Four other dried berry species were also resistant (IS ranged 2.01 – 2.44). In other words, dried cranberries are very unsuitable food for *P. interpunctella*, while other four tested species were slightly more suitable. The content of total sugars in dried berries varied from 24.2% (black chokeberry) to 72.8% (strawberry), but important correlation between IS and total sugar content was not found. By analysing feeding preferences of *P. interpunctella*, we can undertake different pest-management strategies for protection of stored dried fruits.

Keywords: Indian meal moth, dried fruits, infestation, index of susceptibility, susceptibility rating.

Introduction

During all stages of storage process and in all types of storages, dried fruits could be infested by different stored product insect pests like *Plodia interpunctella* (Hübner), *Cadra cautella* (Walker), *Tribolium castaneum* (Herbst) and *Oryzaephilus* spp. Periodically, some polyphagous moths, beetles and mites could also be found (Simmons and Nelson, 1975; Hagstrum and Subramanyam, 2009; Johnson et al., 2009, Almaši and Poslončec, 2010). The most important pest of dried fruits is Indian meal moth, *P. interpunctella* (Johnson et al., 2009), which larvae eat the inside and out of the fruit and cover it with excrements and silk, making it unusable for human diet (Burks and Johnson, 2012). In other words, the biggest losses are in the quality of goods. This moth is of the greatest concern for dried fruits processors (Burks and Johnson, 2012), although studies report that it develops poorly on dried fruits in the laboratory (Arbogast et al., 2005).

In Serbia, the most commonly used dried fruits are prunes, raisins, dried figs and apricots. Recently, different types of dried berries are becoming more popular in human diet and production of dried berries is increasing (Statistical office of the Republic of Serbia, 2018). There are no published data about losses and damages in dried berries caused by *P. interpunctella*. But still, in personal communication with a lot of small producers in Central Serbia, it is emphasized that *P. interpunctella* makes a lot of damages in storages of dried fruits and berries. Besides fumigant control with sulfuryl fluoride and phosphine, the most important methods in control of this pest are sanitation, pest exclusion, sanitary facility design and environmental conditions in storages, especially temperature control (Heaps, 2012).

Dried fruits and berries also have their own susceptibility to infestation by *P. interpunctella*. It depends on the type of fruit, particularly mesocarp density and structure, and also on its nutritional quality and level of moisture. Dried fruits contain > 10% of moisture, which makes them very suitable substrate for the development of this pest. If dried fruits contained < 10% of moisture, it would be more resistant to infestation, but would also be unattractive to human consumers (Sood, 2011). Besides water, dried fruits contain a lot of sugars, commonly > 30% (Cvetković et al., 2009). Proteins and fats, which are very important for insect development, are found in very small amount in dried fruits. Therefore, we hypothesize that the total sugar content could be an important factor that influences the suitability of dried fruits and berries to development of *P. interpunctella*. Based on this hypothesis, the aim of this study was to assess the degree of resistance of five dried berry species (strawberry, raspberry, blackberry, black chokeberry and cranberry) to infestation caused by *P. interpunctella* in correlation with total sugar content.

Materials and Methods

Parental *P. interpunctella* population used in this study was reared for ~50 generations in the Laboratory of General and Applied Entomology, Faculty of Science, University of Kragujevac, Serbia. The population was reared in climate chamber (27 ± 1°C, R.H. 60 ± 10% and photoperiod 14:10 (L:D)), in transparent plastic containers (1.2L in volume) and fed on standard laboratory diet (Silhacek and Miller, 1972). About 100 one-day-old moths *in copuli* were transferred from rearing containers to oviposition jars and one-day-old eggs were used in assays.

Suitability of five dried berry species commonly used in Serbia were tested as a nutrient medium for *P. interpunctella* larvae: strawberry (*Fragaria* × *ananassa* Duchesne), raspberry (*Rubus idaeus* L.), blackberry (*Rubus fruticosus* L.), black chokeberry (*Aronia melanocarpa* (Michx.) Elliott) and cranberry

(*Vaccinium macrocarpon* Aiton), all bought in a local market. 100 mL of each dried berry species were measured and placed into separate glass jars (250 mL in volume). Assays were repeated 12 times for each dried berry species, with a total of 60 replications (jars). In each jar, 50 *P. interpunctella* eggs were added. Jars were then sealed with cotton swab, coated with cotton cloth, for proper aeration. The experiment was carried out in the same environment conditions as described for the rearing of the parental moth population.

Once the emergence of adults began, jars were checked every 24 h and the number of emerged adults and mean developmental duration (MDD) for each adult were recorded. The mean developmental duration was calculated as the average time (in days) from the start of the experiment to the emergence of each adult.

The degree of resistance of five dried berry species to infestation caused by *P. interpunctella* was calculated based on the Index of susceptibility (IS) for insect development (Dobie, 1974)

$$IS = \frac{(\ln(F_1))}{D} \quad 100$$

where F1 represents the mean number of *P. interpunctella* adults that emerged in twelve replications during the experimental period, while D represents MDD. Susceptibility rating (SR) was based on the calculated Indices of susceptibility as suggested by Mensah (1986):

- IS value 0.0 – 2.5 = resistant;
- IS value 2.6 – 5.0 = moderately resistant;
- IS value 5.1 – 7.5 = moderately susceptible;
- IS value 7.6 – 10.0 = susceptible;
- IS > 10 = highly susceptible.

The analyses of total sugar content in dried berries were conducted in Accredited Laboratory (ISO/IEC 17025:2005) of the Center of Hygiene and Human Ecology, Institute of Public Health Kragujevac, Serbia. Total sugar content was determined according to the Luff-Schoorl method for determination of total sugars after inversion, as described in Anonymous (1983). The results are expressed as mass percentage of the sample. Each value was measured three times and averaged with standard error.

Data were statistically analysed using IBM SPSS Statistics 21 software package. Means of Indices of susceptibility and the total sugar content were compared using the Bonferroni test ($p < 0.05$). Correlation between the Indices of susceptibility and the total sugars content was calculated using Pearson coefficient of correlation.

Results

Indices of susceptibility and susceptibility ratings of five analysed dried berry species are presented in Tab. 1. Cranberries were absolutely resistant to infestation by *P. interpunctella* (IS = 0.00). In this assay, one week after the beginning of the experiment, all larvae died. Four other dried berry species were also resistant to infestation by *P. interpunctella*, with higher IS values, ranging from 2.01 (black chokeberry) to 2.44 (blackberry). Index of susceptibility of cranberry was significantly lower than those of four other tested dried berry species ($p < 0.0005$). There were no significant differences established among any of four other dried berry species ($p = 1.0$).

The results of the total sugar content in five dried berry species are presented in Tab. 1. Dried strawberry had the largest content of total sugar (72.8%), while dried black chokeberry had the lowest (24.2%). Correlation between IS and the total sugar content was negative and weak, statistically insignificant ($r = -0.230$; $p = 0.709$).

Tab. 1 Mean values of Index of susceptibility (± SE), susceptibility rating and the total sugar content (%) of five dried berry species to infestation by *Plodia interpunctella*

Dried berry	Index of susceptibility (IS)	Susceptibility rating (SR)	Total sugar content (%)
Strawberry	2.26 ± 0.22 [a]	Resistant	72.80 ± 1.56 [a]
Raspberry	2.37 ± 0.41 [a]	Resistant	51.43 ± 0.80 [d]
Blackberry	2.44 ± 0.36 [a]	Resistant	60.40 ± 0.36 [c]
Black chokeberry	2.01 ± 0.18 [a]	Resistant	24.20 ± 0.52 [e]
Cranberry	0.00 ± 0.00 [b]	Resistant	66.74 ± 0.26 [b]

Vertical mean values of Index of susceptibility and total sugar content having different letters in superscript are statistically different by one-way ANOVA test and Bonferroni test at $p < 0.05$.

Discussion

Due to our knowledge, there are no data about life history of *P. interpunctella* on dried berries, although this moth is one of the most important pests of dried fruits in the world (Hagstrum and Subramanyam, 2009; Sarwar, 2015).

Values of indices of susceptibility and resistance of five tested dried berry species to infestation by *P. interpunctella* could be attributed to their nutritional and moisture content. A few studies showed that nutritional content is of primary importance for successful development of *P. interpunctella*, while moisture content is of secondary importance (LeCato, 1976; Sambaraju and Phillips, 2008; Burks and Johnson, 2012; Predojević et al., 2017). In this experiment, we hypothesized that total sugar content, as major nutrient in dried fruits, could be an important factor that influences the susceptibility of dried berries to infestation by *P. interpunctella*. Our result showed that total sugar content, if used alone as parameter and tested only at five dried berry species, did not show its influence. Sugars are very important for insect development, not alone, but in combination with other nutrients. For example, Arbogast et al. (2005) reported that *P. interpunctella* fails to develop on raisins in the laboratory, while in storage it completes development, thanks to the fungal presence, because the conidia of fungi supports neonate larval development.

In this experiment, five tested dried berry species were resistant to infestation by *P. interpunctella*. Dried cranberry was the most resistant. Value of IS for cranberry was 0.00, because seven days after the beginning of the experiment all larvae were dead. Values of IS of four other tested dried berry species were higher, especially for blackberry (2.44). These results indicate that damages of *P. interpunctella* to tested dried berries were small, but important for the quality of goods, because it makes them much less desirable for human consumption.

Numerous studies showed that some dried fruits are not as suitable for development of *P. interpunctella* as some other types of food (like nuts, maize etc.), especially in laboratory conditions, but still, it is the most important pest of dried fruits. Johnson et al. (1995) reported that prunes are unsuitable food for *P. interpunctella*, because only 0.7% of individuals emerged as adults and MDD lasted between 80 and 160 days. Studies of Johnson (2004), Sambaraju and Phillips (2008), Almaši and Poslončec (2010) and Vukajlović et al. (2017) also indicated that development of *P. interpunctella* on prunes lasts very long, while the number of survived individuals is low. Similar results were published for dried apricots (Almaši and Poslončec, 2010; Vukajlović et al., 2017) and dried cherries (Vukajlović et al., 2017). Recent study showed that dried apricots, prunes and cherries were resistant to infestation by *P. interpunctella*, with IS valued 0.00, 0.78, 1.01, respectively (Vukajlović et al., 2017).

By assessing the degree of resistance of different dried fruits to infestation by *P. interpunctella* and correlating it with physical, chemical and nutritional characteristics of dried fruits, we could gain a real insight in this pest feeding preferences, and consequently in its biology and ecology. On the other hand, by knowing these facts, we can undertake different pest management strategies for protection of stored dried fruits.

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Behaviour of the Angoumois grain moth (*Sitotroga cerealella* Oliv.) in different grain substrates and assessment of losses

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